PERMEABILITY MODELLING AND RESIN INJECTION SIMULATION FOR 3D WOVEN FABRICS

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Introduction

In thick composite components, multiple layers of 2D reinforcements may be replaced by thick three-dimensional (3D) fibrous structures, which may have advantages in terms of toughness and resistance to delamination of the finished component. 3D reinforcements are frequently produced employing weaving processes. They consist typically of layers of aligned low-crimp yarns with alternating orientation along the fabric weft and warp directions, and additional binder yarns, which follow paths through the fabric thickness and provide fixation to the layers. In the manufacture of composite components from 3D weaves, the flow of liquid resin during fabric impregnation is more complex than in thin fibrous structures, in particular because of the presence of the through-thickness binder yarns.

Modelling approaches

One approach for analysis of the impregnation behaviour of 3D weaves implies generating a unit cell model at a high level of geometrical accuracy, e.g. in TexGen. The geometrical model is discretised at a resolution sufficiently high to enable representation of inter-yarn gaps. Voxels are frequently used to avoid geometrical issues which may occur in conformal meshing of complex features. Stokes flow through gap spaces in different material directions is simulated, frequently employing finite volume methods. If the simulation is set up appropriately, results allow accurate determination of the permeability tensor of the fabric [1]. Since the computational cost is high, this approach is generally limited to simulating flow on small domains, such as a single unit cell.

To allow resin flow analysis at a larger scale, Darcy flow is simulated for a fabric with homogenised properties. Here, the permeability is approximated at different levels, taking into account the hierarchical structure of 3D weaves [2]:

- Yarns, including random arrangement of filaments;
- Layers of aligned yarns and voids, modelled with realistic cross-sections;
- Stacks of several layers, where thickness-weighted averaging is employed;
- Disturbances caused by binder yarns.

Effect of binder yarns on permeability

Recent work has addressed modelling the local permeability in stacks of several layers, including effects of misalignment, random variations in the yarn spacing, and drape [3]. This model was now extended to allow for different properties along warp and weft directions of the material. The approach was implemented to generate permeability fields with realistic levels of deterministic and stochastic non-uniformity, which can be used as input for component-scale resin flow simulations using commercial software packages.

However, work presented here focuses on developing a model for predictive description of the effect of the binder yarns on the permeability of a 3D woven fabric. To study the effect of binder yarns on resin flow, “bulk material” is distinguished from “surface material” (Figure 1). Focusing on the geometrically simple example of an orthogonal weave, bulk material shows periodicity (of alternating warp and weft layers and the vertical binder) in through-thickness direction. Surface material is characterised by forming of dimples related to local yarn compression through binder loops on the fabric surface. Based on simulation of Stokes flow, “bulk flow” and “surface flow” is analysed for representative volume elements (RVEs), making use of symmetries to reduce the computational effort where possible (Figure 2). Permeability values derived from simulation results for geometries without and with binder yarns (Table 1) allow the effect of the binder on flow to be quantified. The examples listed here indicate that the presence of the binder results in a 13 % permeability reduction for bulk flow along the warp-direction and in a 4 % reduction for surface flow along the weft-direction. It is to be noted that these values are given for illustration only and that the permeability reduction caused by the binder depends strongly on geometrical parameters of the RVEs.

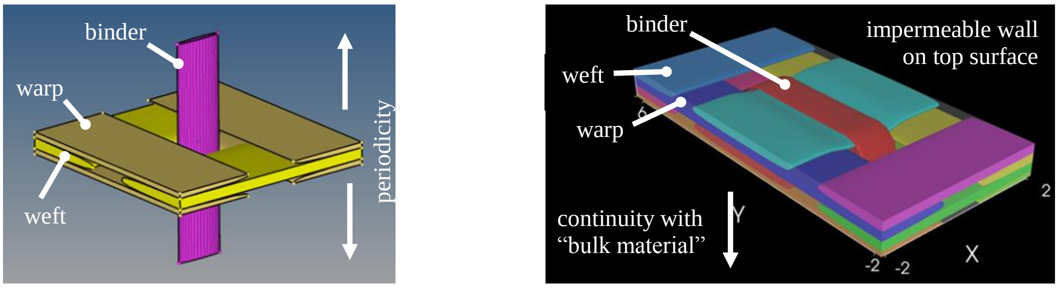

Figure 1: *Examples of representative volume elements of "bulk material" (left) and "surface material" (right).*

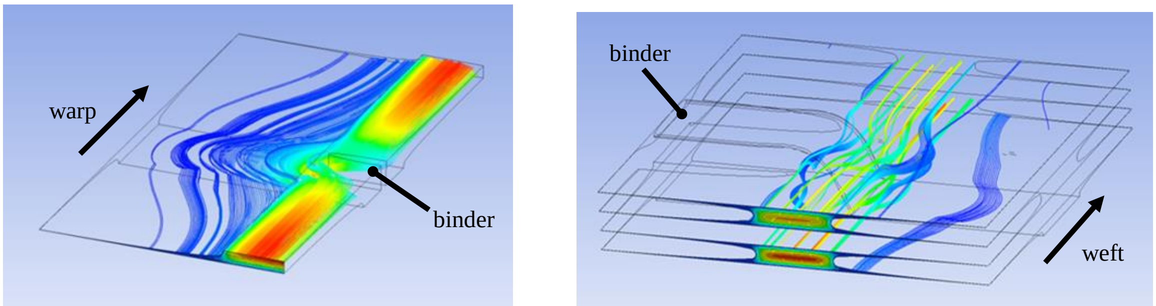

Figure 2: *Examples of "bulk flow" (left) and "surface flow" (right), simulated for the geometries in Figure 1; colour of stream lines indicates local flow velocity.*

Table 1: *Examples of permeability values derived from simulations in Figure 2.*

configuration	permeability / 10^{-9} m^2	
	bulk, warp	surface, weft
without binder	4.05	3.35
with binder	3.54	3.21

Outlook

Based on simulation results for RVEs, local bulk and surface permeabilities of 3D woven fabric will be predicted. These will be used in simplified 3D models for resin injection simulation in medium-size components, where through-thickness variations in properties can be considered without modelling the yarns individually.

Acknowledgements

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References

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